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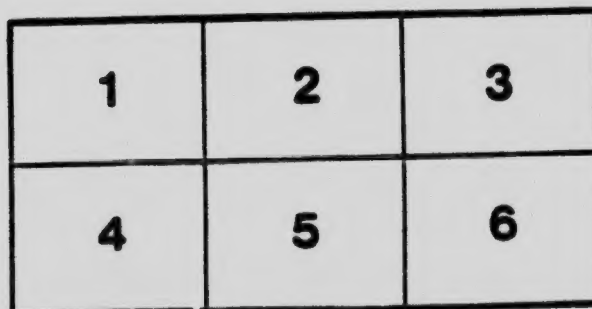
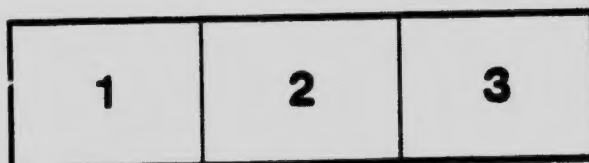
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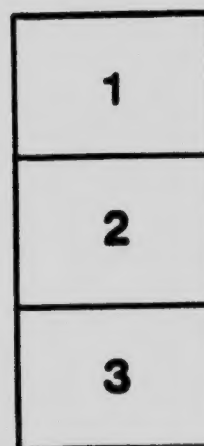
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1916

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# Submarine Boats

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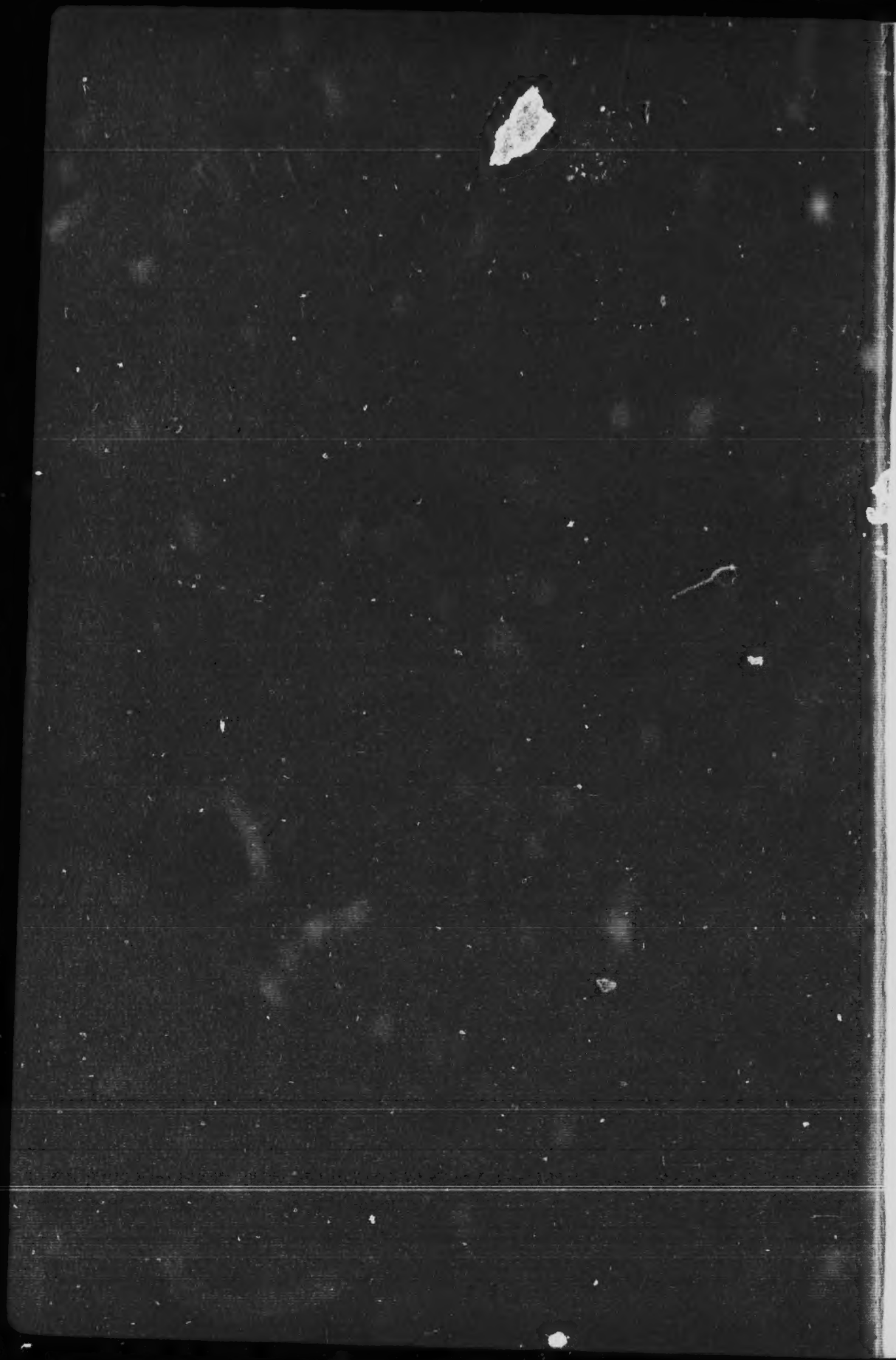
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*From the Transactions of the Royal Canadian Institute, Toronto.*

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1916



## SUBMARINE BOATS

By COMMANDER WILLIAM HOVGAARD

Professor of Naval Design and Construction, Massachusetts Institute of Technology, Boston, Mass.

## I. HISTORICAL REVIEW.

## EARLY BOATS.

(Read January 23rd, 1915).

THE conception of submarine navigation is an old one, and submarine boats have been built and operated fairly successfully several times during the last hundred and forty years. As early as 1624 we hear of a Hollander, Dr. C. J. Drebbel, who constructed a wooden submarine boat propelled by oars. With this boat he experimented on the Thames. Submarine boats, however, did not acquire practical military importance till in this century, because not till then did the technical resources at the disposal of the inventors permit a practical solution.

During the years 1771 to 1775 an American, David Bushnell of Connecticut, constructed a submarine vessel which he called the *American Turtle*. It was built of wood and the shape was that of two tortoise shells stuck together. The boat possessed in a primitive form most of the essential features of modern types. A mine box of wood containing 150 lbs. of gunpowder was carried on the outside and was to be attached with a screw to the bottom of the enemy ship. During the War of Independence an attack was attempted against a British frigate, the *Eagle*, but the operator did not succeed in fixing the mine, which exploded harmlessly at a distance from the ship. Bushnell was the first inventor of the submarine mine. He showed, what was then considered marvellous, that gunpowder could be made to explode under water. He well deserves the title accorded to him as the "Father of Submarine Warfare".

Robert Fulton took up the ideas of Bushnell and with more means at his disposal he advanced the solution of the problem considerably. It is of interest to note that Fulton was a peace advocate, and when he devoted so much energy to the development of the submarine boat as also of the submarine mine, it was on the ground that he believed these weapons would make war on the sea impossible. Other friends of peace have had the same belief. We know now how much they have been mistaken. Fulton went to Paris in 1797 and laid his plans for a

submarine boat before the Directory, but it was not till three years later, when he offered his design to Bonaparte, who was then First Consul, that his plans were seriously considered. Bonaparte saw the possibilities of the new weapon and appointed a Committee consisting of Volney, Monge, and Laplace, who gave a favorable report. A sum of 10,000 francs was appropriated for the purpose and an experimental boat was constructed. The shell plating of this boat was of brass with iron frames. The boat was propelled by hand-driven screws. Fulton descended to a depth of 25 ft. and remained under water for more than four hours. He carried a store of compressed air in a tank for renewal of the air. He blew up a small vessel in the harbor of Brest, attaching a mine to her bottom. In spite of the relative success of the experiments, Napoleon realised that the speed, which was only two knots, was too small for military purposes, and nothing further was done.

During the Civil War in America a number of so-called "*Dauids*" were built by the Confederates. Although referred to as submarine boats, they were probably most of them surface boats, going awash with very little freeboard, showing practically only a cupola above the surface. Some of them were designed for diving, but it is not known that any of them operated successfully under water. Most of the *Dauids* were constructed of iron plates and some were propelled by steam-power. They were built in haste with limited resources and necessarily primitive in construction. They are of interest chiefly because they were actually employed in war and because one of them, a hand-driven boat, succeeded in blowing up a Northern ship, the *Housatonic*.

At the same time the French Government built a submarine boat, the *Plongeur*, which was launched at Rochefort in 1863. The *Plongeur* was of about 450 tons displacement, much larger than any boat built heretofore and thereafter up till a few years ago. The general shape was not unlike that of an ordinary torpedo boat, and it carried a superstructure on top in which was housed a detachable boat to be used in case of emergency. The hull was built of iron plating stiffened by frames. Ballast tanks were fitted for changing the displacement, and the depth was to be kept by two regulating cylinders which produced variations in the force of buoyancy. There were also vertical and horizontal rudders. The boat was propelled by an engine driven by compressed air, whence a very large store of compressed air at a pressure of 12 atmospheres was carried. The engine was of 80 horse-power and operated a propeller which gave the boat a speed of about 5 kts. on the surface. *Le Plongeur* went down to depths of from 30 to 40 ft., she could slide along an even bottom without difficulty, but steering in the vertical plane caused great difficulties. She was the best designed



boat up to that time, but the speed was too slow, the radius of action small, and steering in the vertical plane remained an unsolved problem. The boat, therefore, had no military value and in 1874, after ten years of experiments, the French Government abandoned the project.

#### THE PERIOD FROM 1880 TO 1905.

The greatest difficulty before the designers of submarine boats prior to 1880 was to find a source of power suitable for underwater propulsion. Compressed air, tried in the *Plongeur*, was probably the best available means of storing energy for that purpose, but the air reservoirs occupied too much space, whence the supply of energy that could be carried was too limited. It was, therefore, of the greatest importance for the solution of this problem when in 1880 the French scientist Faure succeeded in improving the lead accumulator, invented by Planté in 1859, by applying a layer of red lead paste as an active material to the lead plates. The accumulator so perfected afforded a means of storing energy eminently adapted for submarine boats since it was independent of the atmospheric air and, although heavy, took up relatively little space.

Another difficulty was that no weapon existed, suitable for a submarine boat. Neither the attachment of mines to the bottom of an enemy's ship, or the use of spar or towing torpedoes offered satisfactory solutions, and ramming was at least as dangerous to the submarine boat as to the enemy's ship. Another great step in advance was, therefore, made when the Whitehead torpedo appeared about the end of the "seventies". This weapon enabled the submarine boat to attack a ship from a distance without difficult and dangerous manoeuvres.

At the same time there was in the "eighties" a strong development in all machinery and fittings used in the application of electric power and light, and great progress was made in the production and storage of compressed air.

Thanks to all these inventions and to the general rapid advance in all fields of engineering which was characteristic of that period, the problem of the submarine boat suddenly became capable of a practical solution. In various parts of the world designs were prepared and experimental boats were constructed, which before the end of the century led to the production of boats practically applicable in naval warfare.

In the "eighties" the author of this article commenced to study the problem\* and worked out several designs of which that of a "diving boat" published in 1888† will be here briefly described in order to

\**Submarine Boats*, London, 1887.

†*On Proposed Designs for Surface Boats and Diving Boats*, Institution of Naval Architects, London, 1888.

illustrate the general standpoint of the problem at that time. It was realised that ordinarily a submarine boat would travel on the surface, and that diving would only be necessary occasionally, namely when in the presence of an enemy. Hence the boat was designed essentially for work on the surface and was given a form very similar to that of a Thornycroft torpedo-boat. A large self-bailing superstructure was fitted on the top, by which a good freeboard and longitudinal stability and hence good seagoing capability were secured. The total reserve buoyancy was about 33 per cent. of the displacement in light condition, half of which was obtained by emptying internal ballast tanks, the other half was due to the self-bailing superstructure which was provided with valves that could be closed watertight. The propulsion was to take place on the surface by steam-power and in the submerged condition by electric accumulators. A combination of electric power for submarine propulsion with another distinctly different source of power for the surface secured at once the military qualities of high speed and great radius of action necessary for bringing the boat to the field of operation of the enemy, and invisibility and perfect protection by going submerged when in the presence of the enemy. The design provided for an armament of two Whitehead torpedo tubes in the bow, giving great power of attack.

The type thus proposed, where principal importance was attached to service in the surface condition, was later perfected, and boats designed on this principle are now generally referred to as "submersibles" in contradistinction to "submarines", which are designed more particularly for submerged work. The characteristics of the two types will be more fully discussed later.

During the "eighties" a Swede, Mr. T. Nordenfelt, built several boats and attained a fair measure of success. He used steam-power for propulsion both on the surface and under water, the steam when in the latter condition being derived from a store of hot water in a reservoir. The system was simple but in order to obtain an appreciable radius of action under water a large store of hot water under a high pressure had to be carried, whence much space and weight were required. Another and serious drawback was that the heat would leak away and the pressure fall in the hot water reservoir in a relatively short time. The Nordenfelt boats were manoeuvred on an even keel, and horizontal propellers were used to secure immersion and to maintain the desired depth. The last Nordenfelt boat, built for the Russian Government, was  $133\frac{1}{2}$  tons and the speed was  $14\frac{1}{2}$  kts.\* The form was very nearly

\*T.L. condition.

\* Figures in the fractions refer to the surface condition, the lower figures to the submerged

ship-shaped, and the superstructure was very long. The control of the motion in the vertical plane was never satisfactorily attained in the No. 1 boats.

In France M. Claude Goubet experimented during the "eighties" and "nineties" with a small type of boat driven only by electricity derived from a battery of primary cells. He was entirely successful and his experience proved of great value to later designers, but the boats were too small and slow to be of military value. The French Government, therefore, rejected his boats, and in 1885 set to work to build submarine boats itself.

The first boat built by the French Government since its attempt with the *Plongeur* was the *Gymnote*, laid down in 1880, a small 30 ts. electrically-driven experimental submarine. As in the Goubet boats the power was at first derived from primary cells, but later a storage battery of iron-copper elements and finally of lead accumulators were substituted. Lead accumulators were here, it appears, used for the first time in submarine boats.

In 1882 a much larger boat, the *Gustave Zédé*, 114 ts., was laid down. She was likewise driven by electricity only and was designed for high speed. The ratio of length to diameter was about 15. Great difficulties were experienced with the storage battery. On one occasion the battery was so badly damaged by short-circuiting that it had to be dismantled, whereupon larger cells of an improved type were substituted. Vertical steering proved very difficult, the boat often took excessive inclinations and hit the bottom on some occasions. Additional horizontal rudders were fitted, so that at last there were rudders both forward and aft and also amidships.

The construction of the next boat the *Morse* was suspended for a long time pending the alterations in the *Gustave Zédé* and was not completed till 1898. The *Morse* was more ship-shaped and carried an optical tube, probably of primitive construction. This was a most important addition to the outfit of the submarine boat, because if further developed it promised to solve, partly at least, one of the greatest difficulties connected with submarine navigation, viz., the complete blindness of the boat when travelling under water. It enabled a boat to approach an enemy within striking distance of the torpedo without the necessity of coming to the surface, showing at intervals only the head of the periscope a few feet above the water.

In 1899 was launched the *Narval*, 114 ts., designed by M. Laubeuf, a French naval constructor. This boat represents in an eminent degree the type referred to before as a "submersible", which term was first introduced by M. Laubeuf to distinguish between his ship-shaped boat



and the previous spindle-shaped boats built by the French Government which he called "sous-marins". The hull is double, consisting of an inner spindle-shaped "strength hull" of heavy construction, calculated to resist the maximum pressures of the water, and a light outer ship-shaped hull which completely envelops the inner. The shape of the aft-body resembles that of a Thornycroft torpedo boat. The space between the two hulls is used chiefly for water ballast, whence a very great reserve buoyancy may be obtained. It was found difficult at first to fill the tanks in a complete manner; whence shifting of air-bubbles were apt to cause violent changes in the longitudinal balance of the boat, and the vertical steering was disturbed. Also the filling of the tanks took nearly one-half hour, much too long for immersing the boat when in the presence of an enemy. These defects were afterwards remedied in the *Narval* and were avoided in later boats of this type. The *Narval* was driven by steam in the surface, where she made 12 kts. The boilers used oil-fuel. Under water she was driven by electric power and attained a speed of 8 kts. She carried four 18-in. torpedo tubes. The heat from the machinery caused considerable trouble. On the whole, however, the *Narval* proved satisfactory and was the type ship for a great number of following boats. Other types of submersibles which have later been developed, such as the Germanian and the Laurenti types, are derived from the Laubeuf boats.

In the United States Mr. John P. Holland worked with great perseverance for a number of years and built several experimental boats. The first, which was very primitive, being worked by hand-power, was launched in 1878. Finally, through the agency of the Holland Torpedo Boat Company, he succeeded in producing a boat that was accepted by the United States Navy in 1899. The boat, which was named the *Holland*, was  $7\frac{1}{4}$  tons; it was cigar-shaped with but a small superstructure on the top and, consequently, had very little stability in the surface condition. The reason of the success of this boat was the use of a gasoline engine for surface work, combined with a storage battery for the submerged condition. Holland first tried steam-power but failed, and the gasoline motor which had just then been developed to a practicable shape was here used for the first time in submarine boats. The gasoline engine had several great advantages; it occupied relatively small space and did not produce so much heat as a boiler and steam engine; it consumed very little fuel so that a great radius of action could be obtained. The engine of the *Holland* was of 50 H.P. and gave the boat a speed of 8 kts. on the surface. The electric motor was of about the same power and drove the boat with a speed of 6 kts. under water. A novelty in this boat was the way in which diving was effected. Contrary to earlier

experimenters who held that the axis of the boat should as far as possible be kept horizontal, Holland boldly effected immersion and emersion by "porpoising", i.e., by inclining the axis, sometimes to great angles, using the horizontal rudder fitted in the stern. This method of controlling the vertical motion proved satisfactory although not without danger, for it has happened that boats of the Holland type took deep involuntary dives. Holland's experiments showed the great importance of keeping the centre of gravity immovable and of compensating for all changes in buoyancy.

The Holland type was reproduced in the United States Navy in the *Adder* Class and following types and in England Vickers commenced building the A-class for the British Navy.

During the "nineties" another American Mr. Simon Lake constructed several experimental boats, and evolved a type of which the *Protector*, 144 tons., built in 1901-2, was the first representative.

The *Protector* belongs to the submersible type, having a ship-shaped superstructure and a reserve buoyancy in the light condition of about 28 per cent. of the light displacement. Diving and emersion takes place as in the *Gustave Zédé* by four horizontal rudders, the boat being always kept nearly on even keel. Mr. Lake's first idea was to produce a boat suitable for salvage operations and the like, and he for this purpose fitted wheels forward and aft hung by pivoted steel jaws fitted in pockets in the bottom and cushioned by hydraulic cylinders. These wheels enabled the boat to run along on an even bottom with a slight deficiency in buoyancy. The means of propulsion are the same as in the *Holland*.

#### MODERN BOATS.

The early development of submarine boats was groping and erratic, the "eighties" and "nineties" was a period of experimentation, resulting in a great variety of types, but after about the year 1900 boats entered into actual military service, with the result that an elimination of the less practicable features took place, and there followed a movement towards a unification of type. At the same time the nautical and military requirements led to a steady increase in displacement and power. Great progress was made in perfecting the various technical appliances. We shall now briefly describe recent types of boats so far as their various features have been made public.

In the British Navy the Holland type was gradually modified considerably. The ratio of length to diameter, which in the A-class was about  $5\frac{1}{2}$ , was much increased. Later boats were given large side structures patched on outside the spindle-shaped strength hull, the object being

probably to gain greater tank volume, greater stiffness in the surface condition, and greater safety against collision. The displacement in the E-class is 111 ts. and in the six boats of the F-class laid down in 1913 it reaches 122 ts. and the speed is 13 kts. No data are known about later boats, but they are probably larger and more powerful.

In the United States the Electric Boat Company developed the Holland type. Boats of the M-class have a submerged displacement of 800 ts. A larger boat of about 1200 ts. displacement is to be laid down this year. The price of this boat is 1½ million dollars. The speed according to press reports is to be 14 kts. The reserve buoyancy of the American Holland boats has been gradually increased and the form of the superstructure is now ship-shaped in the bow.

The Holland type has been adopted also by the *Whitehead* firm in Fiume. The bow of the *Whitehead* boats is similar to that of an ordinary torpedo boat.

The Lake boats have likewise developed to larger size. The *Seal* carries torpedo-tubes in the superstructure.

In France a greater differentiation took place than in other navies. The two main types, the submarine and the submersible, co-existed and were developed simultaneously to greater sizes, but gradually approached each other. After the comparative trials in 1908 between submarines of the *Emeraude* class and submersibles of the *Pluviose* class it appears that the submarine was altogether abandoned. In five boats laid down last year the displacement is 1070 ts.

In Italy submersibles of the Laurenti type have been developed. They have the same principal features as the Laubeuf boats of which they may be considered a variety, but differ from them in some respects. The strength hull is not always circular, although in later boats this seems to be the case. Some have horizontal propellers for submerging. Some recent boats have three propellers for propulsion.

In Germany the Germania firm in Kiel constructs submersibles of the d'Equivilley-Germania type, likewise derived from the Laubeuf boat. The strength hull is cylindrical and is built up of several welded sections without frames. The sections are scarfed together, except one of the sections amidships which is connected to the others by bolted flanges so as to facilitate shipping and unshipping of the machinery. The ballast and fuel tanks are outside the strength hull amidships and at the ends. Only one internal tank, used for compensating for incidental variations in buoyancy, is fitted amidships. The boats dive almost on an even keel. The latest German boats are probably of about the same size as the English F-class.

## II. A DISCUSSION OF THE PRINCIPAL FEATURES OF THE DESIGN OF SUBMARINE BOATS.

### SUBMARINES AND SUBMERSIBLES.

The "submersible" has already been defined as a submarine boat in which predominant importance is given to the requirements of service in the light condition, while the "submarine" is designed more particularly with regard to the submerged condition. Hence the ship-shaped form of the submersible and the spindle-shaped form of the submarine. The external ship-shaped form of the submersible is however attained without abandoning the advantage of the circular section which is maintained throughout an inner spindle-shaped "strength-hull", because it is the form best adapted to resist the pressures of the water. Between the inner and the outer shell are water-ballast tanks and oil tanks, whence the strength hull may be of small diameter well suited to resist great pressures without going to excessive scantlings. The outer hull, not being exposed to great pressures, may be lightly built and will yet in some measure protect the inner hull against damage by collision. At the same time the ballast and oil tanks may, with a relatively small addition in hull weight, be made very large, whence a great reserve buoyancy and great radius of action can be secured. In a submarine the tanks are chiefly inside the strength hull and cannot, therefore, be very large without unduly increasing the diameter of the hull and hence its tendency to collapse.

Speaking broadly, the submersible has better seagoing qualities and a higher speed on the surface than the submarine, but the form is not so favorable for driving under water. Most early boats were submarines. It was natural that inventors, especially those not acquainted with the requirements of naval service, should direct their efforts especially to navigation under water and that they should underestimate the importance of qualities required for work on the surface. At present the general trend of the development is towards the submersible type. Of recent years, therefore, the submarine, where it is still retained, has approached more and more to the submersible by an enlargement of the superstructure, which at the same time has been given a more ship-shaped form. In English submarines side structures have been added. The reserve buoyancy in the early submarines was only about 5 per cent. of the light displacement, but has been gradually increased to about 18 or 20 per cent. In submersibles, on the other hand, the reserve buoyancy has been reduced from about 72 per cent. in the *Nautilus* to about 35 per cent. or less in recent boats.

The submersible has a rather high centre of gravity and in submerged condition a low metacentre (centre of buoyancy), and hence small stiffness on account of the high position of the ballast tanks, while in the surface condition the stiffness is in some cases excessively great owing to the large area of the water-line. The submarine has a lower centre of gravity and, due to the low lying water tanks, it has a high metacentre in the submerged condition and small or moderate stiffness on the surface. The Laurenti type, where the ballast tanks are partly below the strength hull partly above or very high, are intermediate between the Germania and the Holland type in this respect.

In order to obtain sufficient stability in the submerged condition submersibles must generally carry a considerable amount of keel-ballast. This of course is a drawback, but also most submarines carry some ballast. Part of the ballast is generally detachable, often referred to as a "safety keel", to be let go in case of emergency. In passing from the light to the submerged condition and *vice versa* a point will exist where the stability is a minimum, being reduced by the presence of free water in the tanks. The designer must, therefore, carefully determine the conditions of stability in all intermediate positions in order to satisfy himself that a proper metacentric height is always maintained. If the stability vanishes at any point the boat may heel over to a considerable angle before equilibrium is restored or may even capsize.

#### STRENGTH OF HULL.

The hull of a submerged vessel is exposed to an external water pressure which is directly proportional to the depth of immersion. Already at a depth of 200 ft. the pressure is about 100 lbs. per sq. in., and since the depth of water in the ocean is generally more than 10,000 ft., boats cannot be constructed to withstand the pressures at all depths which they may encounter. It is therefore necessary to assign a limit to the pressure head which a boat is required to resist. Generally boats will have no reason to go deeper than required to clear the bottom of vessels on the surface, that is to a depth of about 75 ft., but accidentally they may descend involuntarily to greater depth. Usually the head to which submarine boats are tested is about 150 ft., although in some navies it is as much as 200 ft. A certain margin of safety is of course applied in the construction, but if the boat goes much beyond its test depth it is liable to collapse.

In most boats the strength hull is of circular section as stated above. The Whitehead boats and other boats of the Holland type have internal frames. As seen from the midship section of the Danish boat *Havmanden*, the Whitehead boats in some cases have oval sections



even amidships, because this form is convenient for boats designed for operating in shallow water. Some boats, such as those of the Germania type, have no frames. Other boats such as those of the Laurenti type appear to use the framework between the inner and outer hull as a means of stiffening the strength hull.

#### STEERING AND NAVIGATION.

Steering in a horizontal direction takes place as in ordinary vessels, but steering in the vertical plane has caused many difficulties to early inventors. As late as 1901 a German authority, Professor Busley, deprecated the value of submarine boats on that ground.\* Mr. Holland introduced diving and emerging by inclining the boat at considerable angles, while most other inventors preferred to keep the boat as nearly as possible on an even keel and to effect great changes in depth by pumping water in or out of the boat, by means of horizontal propellers, or by so-called "hydroplanes". The last method is that which at present is mostly used in submersibles. Hydroplanes are similar to rudders—sometimes fitted amidships abreast of the centre of gravity of the boat, sometimes placed forward and turned the same way as the aft rudders. In all cases the object is to obtain an upwards or downwards force driving the boat laterally up or down. This method is generally considered safer than the "porpoising" used in the Holland boats. Once the desired depth is attained it is preserved by using the horizontal rudder in the same way as when steering a course on the surface, but with this difference, that even small deviations from the given course line (depth) are not here permissible. For guidance in steering a depth gauge and a clinometer are used. Steering in the vertical plane requires considerable skill and experience.

In order to navigate, the submarine boat must be provided with a reliable compass and, even when submerged, a view of the horizon must be obtainable at any time. An ordinary magnetic compass is not quite reliable even when placed in a conning-tower of bronze, but recently the advent of the gyroscopic compass has provided a means of accurately determining the direction. The faculty of vision when the boat is submerged, as it must be when making an attack, constitutes one of the most important and difficult problems connected with submarine boats. The water is practically opaque and it was therefore necessary in early boats, when going under water, to emerge from time to time so as to obtain a view from the conning-tower, but evidently this mode of navigation was anything but safe, since the presence of the boat was thus revealed to the enemy. Already in the "eighties" and "nineties" optical

\*Transactions of the Institution of Naval Architects, London, 1901, p. 188-189.

tubes were introduced of simple construction, invented by Marié Davy in 1854 and gradually perfected. In its simplest form the optical tube had a mirror at each end inclined at  $45^\circ$  to the axis. The tube, being fitted watertight in the top of the boat, projected a foot or two above water when the boat was immersed to a certain depth and thus a view of a part of the horizon might be obtained, but the angle of vision was only one or two degrees, and the image was very imperfect. The mirrors were replaced by prisms, lenses were introduced and during the "nineties" several improvements were made, but not till about ten years ago was any serious progress made. Then in a few years the optical tube, or the "periscope" as it is now usually called, was developed to a high degree of perfection, enabling the submarine boat to perform attacks without showing anything but the top of the periscope occasionally above water, at the same time obtaining a perfect view of the enemy. The periscope was the last link in the chain of inventions which were needed to give to the submarine boat positive military value. The improvements in the periscope comprise a larger field of vision spanning an arc of more than  $50^\circ$ , as large as or greater than that of the human eye, convenience of observation, and the addition of means for measuring distances and indicating directions. The magnification of the object is only about 1.5, which is found to give to the observer the same impression as when using the naked eye. By using the utmost refinements of optical art and science a perfect image of unsurpassed clearness and distinction is obtained. Mechanical power is used for handling the tube, enabling it to be pushed up and down readily and quickly and to be turned round its axis. The length of modern tubes is up to 25 ft. with a diameter of about 6 in. The head of the tube projects from 15 to 22 ft. above the superstructure. Difficulties still exist due to the vibration of the boat and due to spray on the front glass, but they are of secondary importance. Instruments have been constructed by which an all-round view of the horizon can be obtained without turning the tube, but have not proved quite satisfactory.

#### VARIATIONS IN BUOYANCY.

In order to go from the light to the submerged condition and *vice versa* it is necessary to admit or to discharge water. Main tanks of great capacity must therefore be found provided with large sea-valves and powerful pumps. Means are provided also by which the water may be forced out of the tanks by admitting compressed air. Ordinarily the air is not admitted till the boat is on the surface, where only low pressure air is required, but a sufficient store of highly compressed air is carried by means of which the tanks can be emptied very quickly

in case of emergency, even when the boat is at a great depth. The time occupied in passing from the surface to the submerged condition should be not more than about from 4 to 5 minutes. This, of course, is a point of great military importance. Since the main tanks are always filled completely when it is desired to dive, it is necessary to fit one or more auxiliary or regulating tanks of moderate capacity to allow for variations in the specific gravity of the water and for changes in the weight of the boat due to consumption of provision, stores, etc. The consumption of fuel-oil is roughly compensated for by admitting water to the bottom of the oil tanks, which are thus always kept completely filled. The buoyancy of the boat in the submerged condition is so adjusted that a small "reserve buoyancy" remains, leaving always a tendency to rise to the surface. This tendency is overcome dynamically when the boat is in motion either by hydroplanes or by giving the boat a slight downward inclination by the head.

Small tanks, one at each end of the boat, permit an accurate adjustment of the trim (the longitudinal balance). Special tanks are fitted for compensating for such losses in weight as when a torpedo is fired and another is inserted in the tube. In some boats a so-called "floating tank" is fitted, connected with a continuously acting pump which is worked in conjunction with the horizontal rudders; this tank serves to compensate automatically for incidental variations in buoyancy occurring after the boat has got under way, notably those due to changes in the specific gravity of the water. A considerable amount of buoyancy can be obtained almost instantaneously in case of emergency by the release of the safety-keels referred to above.

The superstructure which is above water in the light condition is self-bailing. In some boats it is entirely and permanently open, serving only to provide a raised platform, but in most boats it is a watertight structure provided with large and numerous valves that can be readily closed when the boat is in light condition whereupon the superstructure will add to the reserve buoyancy and the stability.

#### VENTILATION AND HABITABILITY.

Space is always restricted in a submarine boat. When going on the surface the motor gives off much heat and requires a great amount of air for its combustion. It is unavoidable that some of the products of combustion, carbon monoxide and carbonic oxide, leak out from the engine. Also the men consume oxygen and produce carbonic oxide, and when charging the batteries free hydrogen is liable to be liberated, forming with the air in the boat an explosive mixture. Where the fuel is gasoline or other very volatile oil, it will evaporate at a low tempera-

ture and is liable to leak out into the boat; it is poisonous and is capable of forming an explosive mixture with the air. Hence it is necessary to provide very vigorous ventilation when going on the surface. In the submerged condition the problem would appear to be even more difficult. The available air gradually becomes vitiated, but it is found that the crew can live for several hours without any sort of air renewal or means of purification. This is due to the constant leakage which takes place from the compressed air system, a leakage which can never be entirely prevented. If desired, the carbonic acid, which gradually accumulates due to exhalation, may be removed by chemical means, or the foul air may be pumped out. Fresh air can be supplied from the compressed air reservoirs. There is, however, rarely occasion for resorting to such means. A greater difficulty is the escape of gasoline and poisonous fumes from the motor as well as from the battery. There is no convenient test for carbon monoxide suitable for use in submarine boats, whence it has been necessary to use white mice for indicating the presence of this poisonous gas to the effects of which these little animals are very sensitive. White mice breathe much more vigorously than human beings and will absorb carbon monoxide about twenty times as rapidly as man. Hence, long before man feels any discomfort, the mice will show symptoms of distress. When this occurs, and especially when the mice become asphyxiated it is time to ascend to the surface and to renew the air in the boat.

With proper precautions the crew may remain in the boat with all hatches closed for 12 hours or more, which is generally all that is required, since the boat can go to the surface as soon as darkness sets in.

Life on board a submarine boat is, however, very fatiguing and for this reason the time in which a boat can stay away from its base is very limited. The crew has to be changed at frequent intervals or it must be given time to recuperate, a fact which in many cases may limit the practical endurance of the submarine boat more than the supply of fuel. As matters stand now it may be said that the crew of a submarine boat ought to be relieved after two or three weeks' service.

#### PROPULSIVE MACHINERY.

For propulsion on the surface the gasoline motor was the first really successful engine. It was light, occupied small space as compared with the steam machinery and the combustion of fuel-oil was not more than about one-half pound per H.P. hour as against at least  $1\frac{1}{2}$  lb. per H.P. hour for steam machinery with oil-fed boilers. For small boats, of a displacement of from 100 to 300 ts. where weight and space were very restricted, the gasoline engine offered the best solution, but the

dangers by this volatile oil soon made it necessary to introduce heavy-oil motors, although they were in several respects inferior to the gasoline motors. While the latter are easy to start, special means are required for starting the former, and the consumption of fuel in heavy-oil motors, as for instance of the Koerting type, was about twice as great as in the gasoline motors. The last step in the development was the introduction of the Diesel engine, which although rather heavy and likewise burning heavy oil, has a consumption of fuel somewhat less than that of the gasoline engine. The nominal radius of action of recent boats of the largest size, driven by Diesel motors, is given as from 3000 to 5000 miles. The speed on the surface has attained 16 kts. in several boats and the designed speed in some boats now under construction is 18 or 20 kts.

The Diesel engine is the motor which to-day finds most favour in submarine boats, but with the increasing size of boats and the claims to higher speed it becomes increasingly difficult to produce motors of sufficient power. Units of from 800 to 1200 H.P. are under construction and there are usually two and in some boats three propellers. Many difficulties are met with and failures have occurred, whence steam power has been preferred in some boats as for instance in the French submersibles *Gustave Zédé* and *Nereide* of 1000 ts. displacement, which are to make 20 kts. Steam machinery has the advantages of reliability and durability, but it occupies much space and the problem of getting rid of the heat is difficult to solve. The radius of action obtainable with steam power on a given weight of fuel is much smaller than with Diesel motors.

The weight of Diesel engines as fitted in submarine boats is about 65 lbs. per H.P. as compared with about 50 lbs. per H.P. for gasoline engines and from 50 to 60 lbs. per H.P. for steam machinery inclusive of propellers and shafts.

For under-water propulsion electric power derived from a storage battery of lead accumulators still offers the best solution. Since the first appearance of these cells they have been improved upon in many technical details, and are now reliable and durable. They will stand complete charging and discharging more than 400 times, and under ordinary peace service conditions if carefully handled they may be expected to last about 5 or 6 years. The weight per H.P.-hour including outfit is by discharge in  $3\frac{1}{2}$  hours about 80 lbs., practically the same as in early accumulators. Lead cells permit great variations in power and are at their best at low rates of discharge, a most valuable quality for submerged work. They can be stowed low in the boat and add thus considerably to the stability. They occupy about 0.4 cb. ft.

per H.P.-hour, i.e., less than any other source of energy at present available for this purpose.

Attempts have been made to introduce accumulators of different type but so far without success. The Edison alkaline iron-nickel cells are about 10 per cent. lighter, but occupy at least 25 per cent. more space; they cannot be so rapidly discharged as the lead accumulators. They cost more than three times as much, but are more durable. It appears that recently improvements have been made and better results are claimed by the makers. Practical service tests are required to determine the relative merits of these cells.

The total energy accumulated by storage batteries is necessarily small and rarely allows more than a speed of about 10 kts. for 3 or 4 hours. Recently boats have been designed for 11 or 12 kts. The radius of action at maximum speed of large boats is about 30 or 40 miles, at reduced speed about 100 miles.

The excessive weight of the plant for underwater propulsion is the more unfortunate, since the weight available for propulsion is already very small as compared with that in ordinary torpedo-boats. The reason for this is that the hull weight is extremely great, occupying about 20 per cent. more of the total displacement than in an ordinary torpedo-boat. Only about 30 per cent. of the displacement of a submarine boat can be devoted to machinery and fuel as against about 50 per cent. in a torpedo-boat. Moreover the plant for underwater propulsion comes as an extra addition. It is evident, therefore, that submarine boats can never compete with torpedo-boats as to speed and radius of action.

Great efforts are being made to devise a type of machinery that can be used both on the surface and submerged and especially one by which the propulsion under water does not entail any extra weight, but no satisfactory solution has yet been obtained. Any process based on combustion involves the storage of atmospheric air or oxygen, but a storage of these gases in sufficient quantities for underwater propulsion requires excessive weight and space. The discharge of the products of combustion is liable to reveal the presence of the boat.

M. d'Equivilley has proposed a solution which is being tried in the French submersible *Charles Brun* and probably also in a German boat.\* He uses an ordinary boiler with oil fuel and a steam engine on the surface, but when the boat dives under water the exhaust steam is led to a concentrated lye of sodic hydrate ( $\text{NaHO}$ ) which absorbs the steam under strong evolution of heat and thus serves as fuel in a secondary "soda boiler". This process goes on till the lye is saturated. When

\* *Jahrbuch der Schiffbautechnischen Gesellschaft*, 1913, pp. 131-136.



the boat comes to the surface and steam is available from the primary boiler, the soda lye may again be concentrated by evaporation of the water which it has absorbed, and the boat is ready for another submerged run. This plan offers the advantages that there is no change of motor, the same engine being used under water as on the surface, and there are no products of combustion. The machinery can be forced without difficulty and relatively high power attained both in light and submerged condition. No electric motor is needed. On the other hand, the system requires the addition of special soda-boilers and a hot water reservoir; the plant occupies so much space that the available weight cannot be fully utilised; the centre of gravity of the machinery is high and requires extra ballast to be carried; the radius of action on the surface is necessarily smaller than with an explosion motor; there is likely to be a strong corrosion due to the soda, and isolation for heat will probably cause difficulties. The soda-boiler plant appears, however, more promising than other power plants so far proposed for this purpose.

#### ARMAMENT.

The principal armament of submarine boats is the Whitehead torpedo. English boats of the F-class are said to carry six 21 in. tubes and French boats of the latest type eight tubes. Recently large submarine boats have been equipped with an armament of light guns in disappearing mountings. Later English boats carry two 3-in. guns so mounted that they can be used against air-craft as well as against other vessels. When not in use, the guns and mounts are housed in the superstructure.

Attempts have been made to design mine-laying submarine boats, a problem which is evidently of considerable interest. As far as known, Russia is the only power that prior to the war had built a boat for this purpose, viz., the *Krab*, designed for dropping mines when in surface condition. A boat so designed that mines could be dropped when in the submerged condition would be of greater value, but there are technical difficulties in releasing mines under water, in compensating for their weight and in determining their exact location.

#### SIGNALLING.

The faculty of communicating with other vessels whether on the surface or submerged is one of great military importance for the submarine boat. For service on the surface wireless telegraphy has been successfully used for several years, but for submerged service it is only quite recently that means of signalling has been devised which seem to

promise good results. It was at first, when the submarine bell was invented, attempted to use it for signalling, but it was found that it was not well suited for sending messages by the Morse system. No practicable solution was discovered till an Austro-Hungarian physicist, Mr. H. C. Berger, showed the way by his experiments undertaken in the Danube at Budapest on the transmission of longitudinal vibrations through water. A wire of 2 in. in diameter was set into vibrations by the friction of a hand-driven silk-wheel moistened with alcohol whereby a clear and sustained note was produced, capable of being sent in dots and dashes of the Morse code. The wire was fastened to a plate in contact with the water, and was anchored at the other end to some fixture, but the tension of the wire was immaterial. The identical apparatus used by Berger was fitted in one of the United States submarine boats in 1911 and readable signals were transmitted over a range of two miles. Still better results were obtained with steel ribbons and power-driven exciters, by means of which distinct signals were transmitted over a distance of 10 miles. Recently electrically-worked oscillators, invented by Professor R. A. Fessenden, have been used instead of the wire ribbons and have given very promising results. This mode of signalling is sometimes referred to as the "submarine wireless system", but it must be distinctly understood that the transmission through the water takes place entirely by sound waves emanating from a diaphragm plate which may be part of the ship's side. The receiver is a similar plate in another ship similarly connected. This appliance is now being developed by the Submarine Signalling Company of Boston and, apparently, with considerable success.

#### SAFETY, SALVAGE, AND TRANSPORTATION.

As a consequence of the numerous and serious accidents which have befallen submarine boats of recent years, much has been done to increase the safety of this craft. The hull is subdivided more minutely than formerly by bulkheads of sufficient strength to withstand the maximum water pressure. A buoy provided with telephone connection is fitted in the superstructure and can be sent to the surface in case of emergency, enabling communication to be established with the outside world. In some boats the men are provided with diving suits and helmets, enabling them to escape or to remain for a longer time in the boat when it is flooded. Great precautions are taken to prevent the fumes from the storage battery from entering the working rooms of the boat. The battery is in many boats placed in an entirely separate, airtight, well ventilated compartment. Vessels of special type, "salvage docks", are built for the purpose of raising the boats when they have sunk to

the bottom in damaged condition. Shackles are fitted on the top of the boats for this purpose.

Special vessels are constructed also for the transportation of submarine boats.

#### SIZE.

From the moment that submarine boats were taken into practical service, claims to increased seagoing capability, speed, radius of action, and better living conditions on board were advanced by the naval officers. These claims could be best met by an increase in size and we can understand, therefore, that size has steadily increased ever since the beginning of the century. Boats were then less than 100 ts. fully submerged and are now being built of about 1200 ts. displacement. The reason why the displacement has not increased much faster is chiefly the difficulty of providing motors for propulsion of sufficient power. By an increase in size, moreover, the boats become more difficult to handle under water, especially where the depth is small, but probably this difficulty would be of secondary importance for ocean-going boats, should such boats become a reality. The high cost of large boats will put an early limit to their number, the price per ton being almost three times as high as for battleships.

#### MILITARY VALUE.

The great military value of submarine boats has been demonstrated in the present war. At the present stage of development submarine boats afford not only the best means of defence of our own harbors and coasts, but may be used also for offensive purposes in the open sea and on the coasts of an enemy up to a distance of some five hundred miles from their base. The large boats of about 1200 ts. displacement now under construction probably have a still greater radius of action.

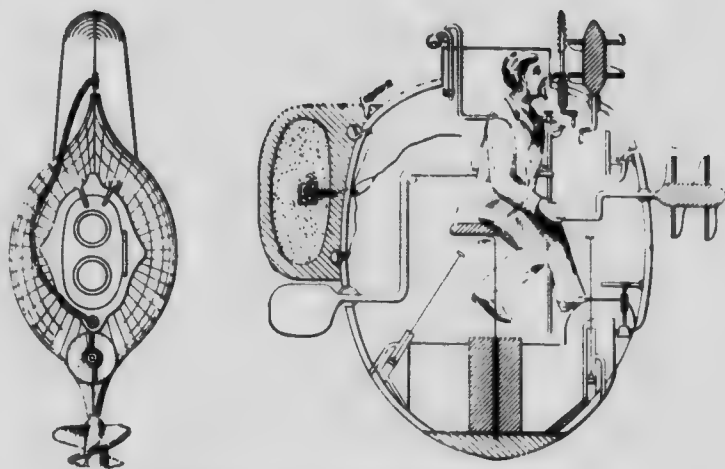
A peculiarity of the submarine boat is its faculty to carry out an attack with relatively small risk once it has gotten into position, in which respect it differs radically from the ordinary torpedo boat which must always be prepared for great and almost unavoidable sacrifices in order to carry out a successful attack. The greatest difficulty with a submarine boat is to bring it into position for attack.

The future development of the submarine boat is likely to be steady but slow. In the meantime it is probable that also the means of attack and defence possessed by the battleships against submarine attack will progress. Evidently, the first point for the battleship is to detect the submarine boat. Once detected before it has reached within striking range the submarine boat can generally be avoided,

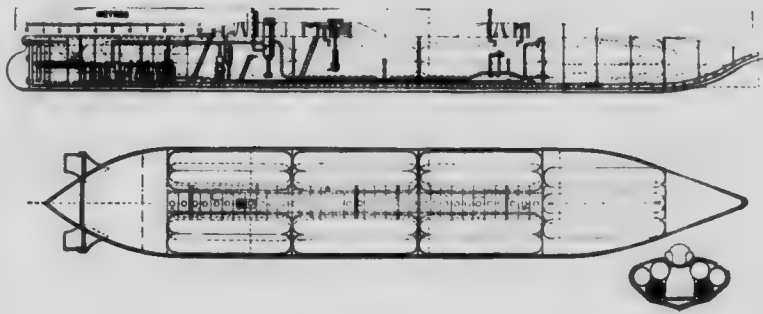
because its speed under water is so slow relative to that of the battleship. The detection of a submerged boat is, however, a difficult matter, the only visible point being the head of the periscope, which needs to be shown above the surface only from time to time. In still water the periscope is fairly visible by the wake which it makes on the surface when emerging, but in rough and misty weather it is extremely difficult to detect. Detection from air-craft is under certain circumstances fairly easy and this mode seems to promise a great deal. When the periscope is discovered, it will be at once subject to a hail of projectiles from light guns, and if it is hit the boat will be blind and helpless. If, after that, the boat shows its conning tower above the surface, it will generally be exposed to destruction by artillery fire.

Seaplanes or other types of air-craft may possibly become a dangerous enemy of the submarine boat not only in helping to detect it but also by direct attack with bombs. When the boat is submerged it is quite helpless against bomb dropping. Even very light bombs are likely to prove destructive, and since the air-craft is in no danger of counter-attack from the submarine boat, it can go very low and hitting should not be a difficult matter. The submarine boat cannot even observe a seaplane when immediately over it. A further development of the seaplane is, therefore, likely to prove extremely dangerous to the submarine boat. Numerous small patrol-boats properly equipped for attacking the submarines with gun, ram and other weapons are likely to prove effective in the vicinity of the coasts.

While the active or offensive means of defence are in this case as elsewhere the most effective, the battleship possesses means of defence of a passive nature such as watertight subdivision, elastic bulkheads and underwater armour, which may be still further developed, but experiments and war experience are required to throw light on the problems involved. The superior speed of battleships is of course in itself a means of protection. On account of the present limited range of submarine boats and perhaps especially on account of the limit to the endurance of the personnel, they do not render the powerfully armed and well protected artillery ships superfluous. Large seagoing battleships and battle cruisers are yet required in order to control the ocean, but as matters stand now, the smaller enclosed seas such as the Baltic, the North Sea, the Mediterranean, the Yellow Sea and other similar waters may be practically controlled by submarines and by light, fast vessels. In the presence of an active enemy well provided with submarine boats large vessels cannot operate in such seas except under the greatest precautions, going at high speed and using all possible means of defence.



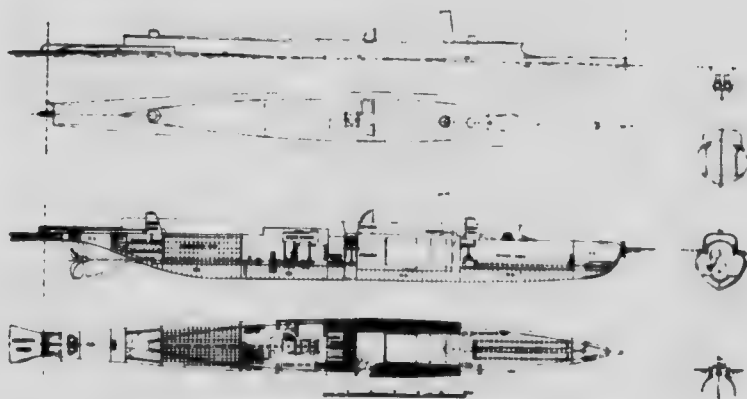
BUSHNELL'S BOAT: THE AMERICAN TURTLE.



LE PLONGEUR.



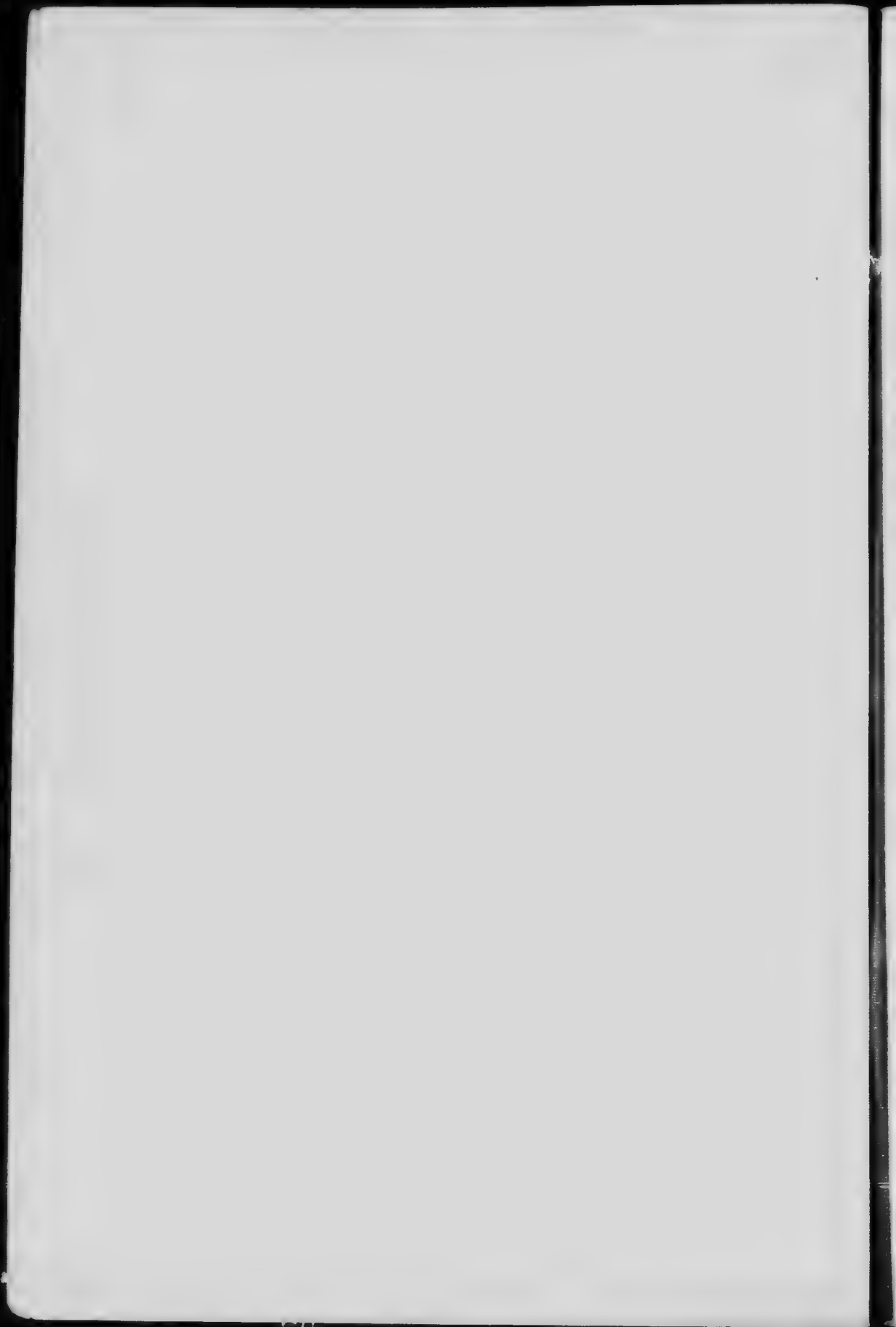


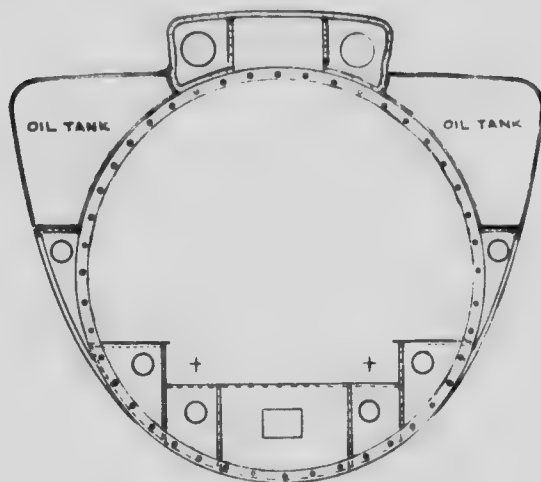


DIVING BOAT PROPOSED BY THE AUTHOR IN 1888.

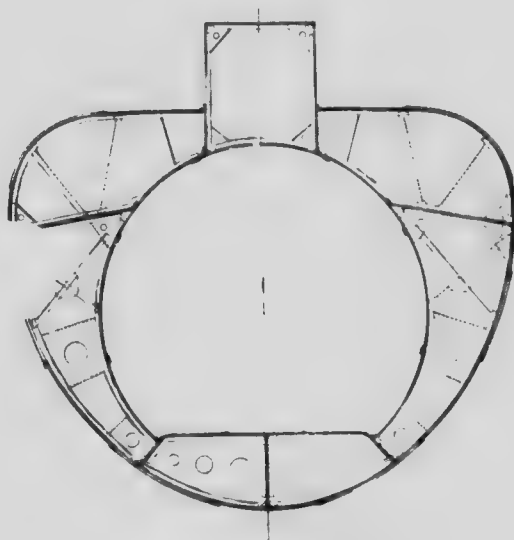


THE NARVAL: THE FIRST LAUBEUF BOAT

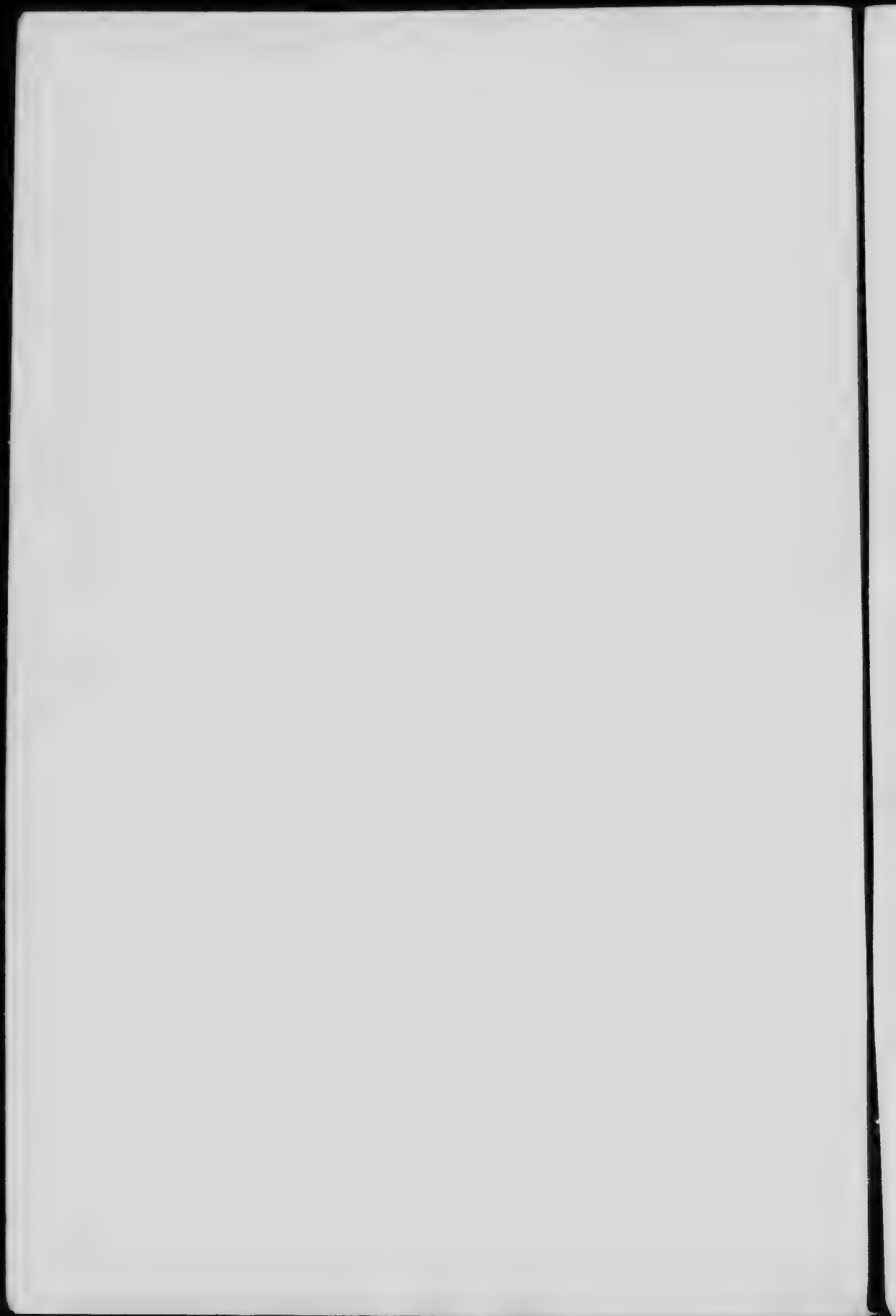


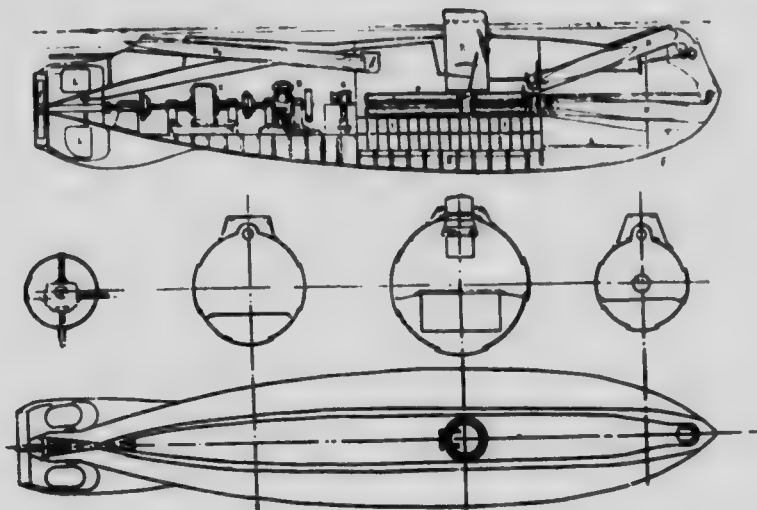


SUBMERSIBLE OF GERMANIA TYPE.

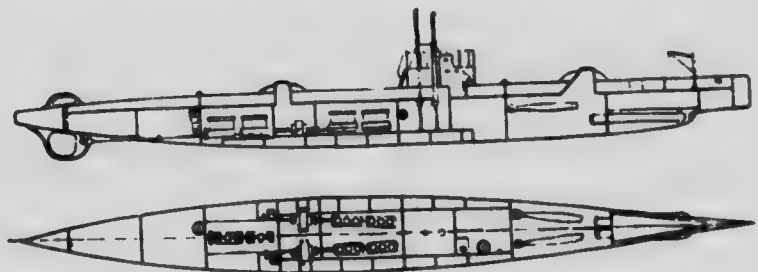


SUBMERSIBLE OF LAURENTI TYPE.





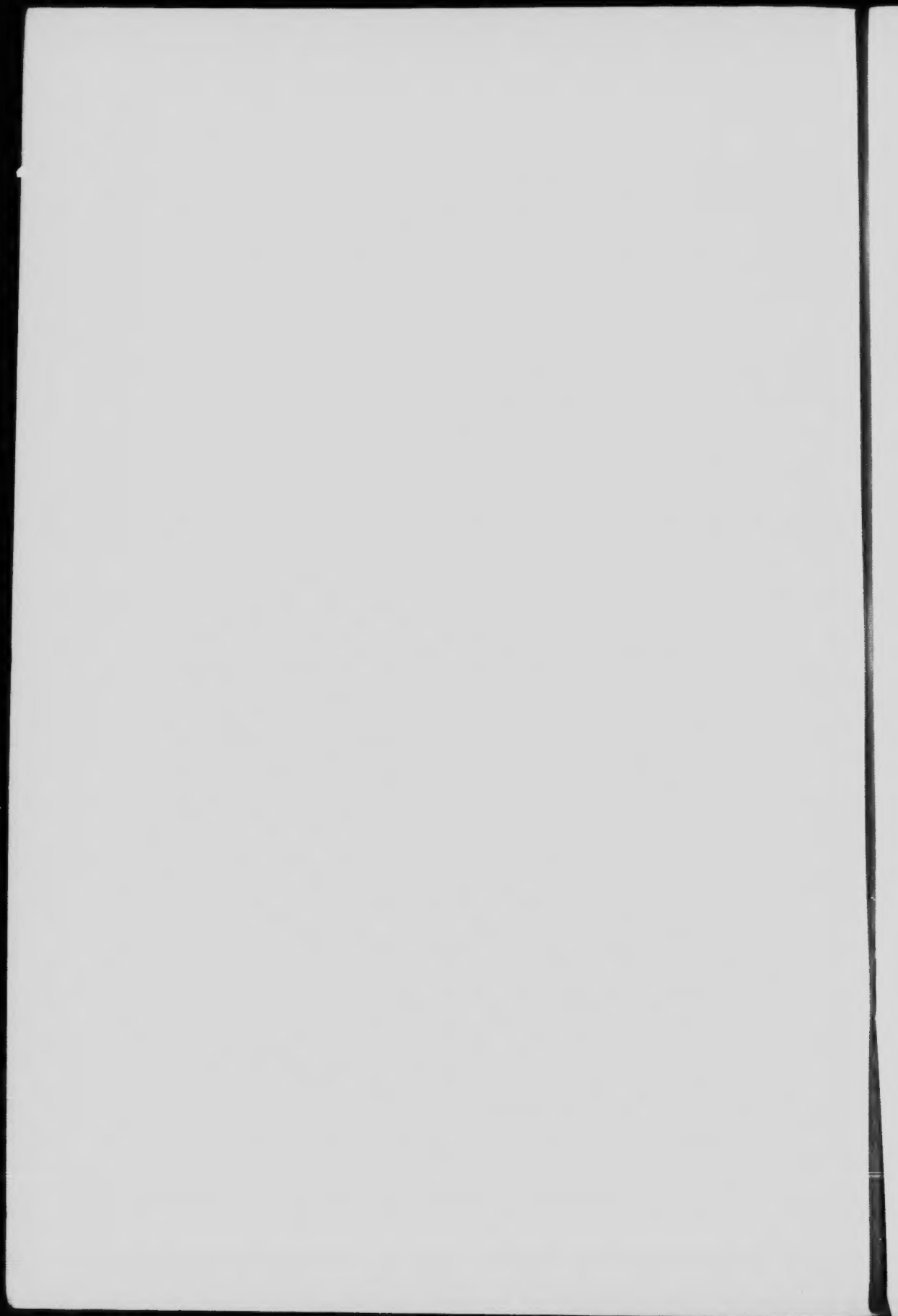
THE HOLLAND.

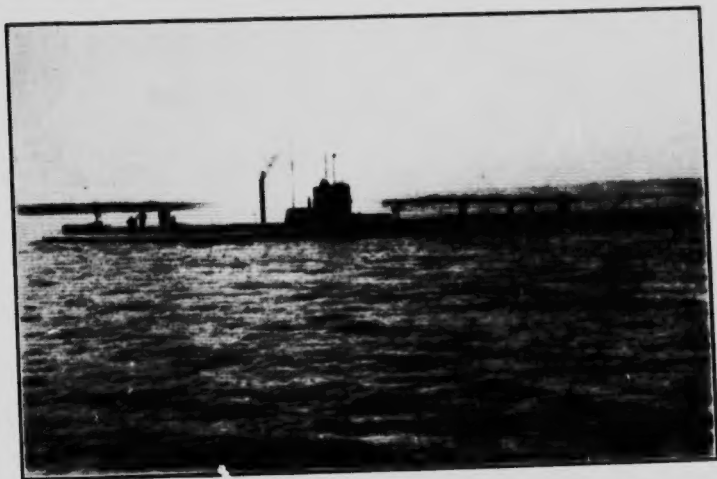


THE FOCA: ITALIAN SUBMARINE.

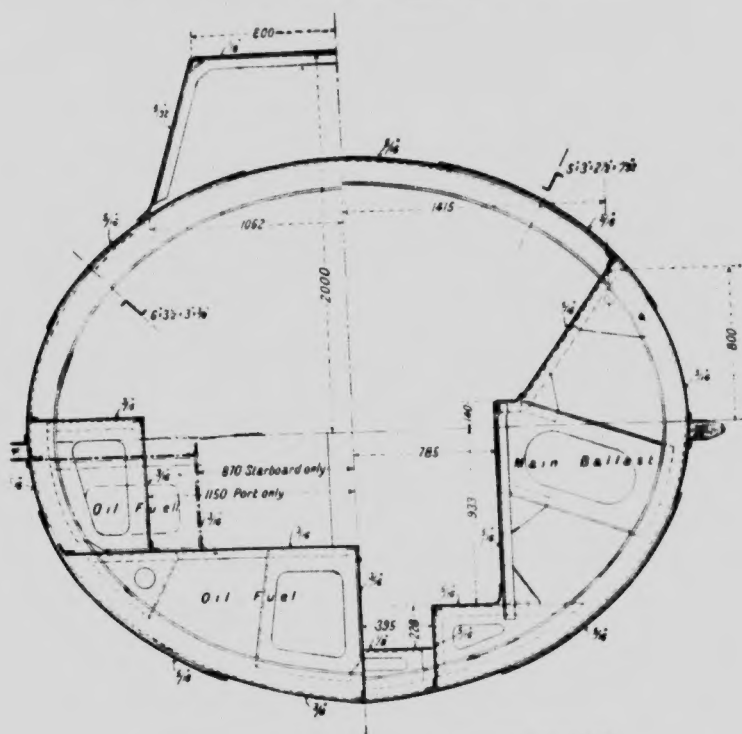


H.M. SUBMARINE-BOAT E 4.



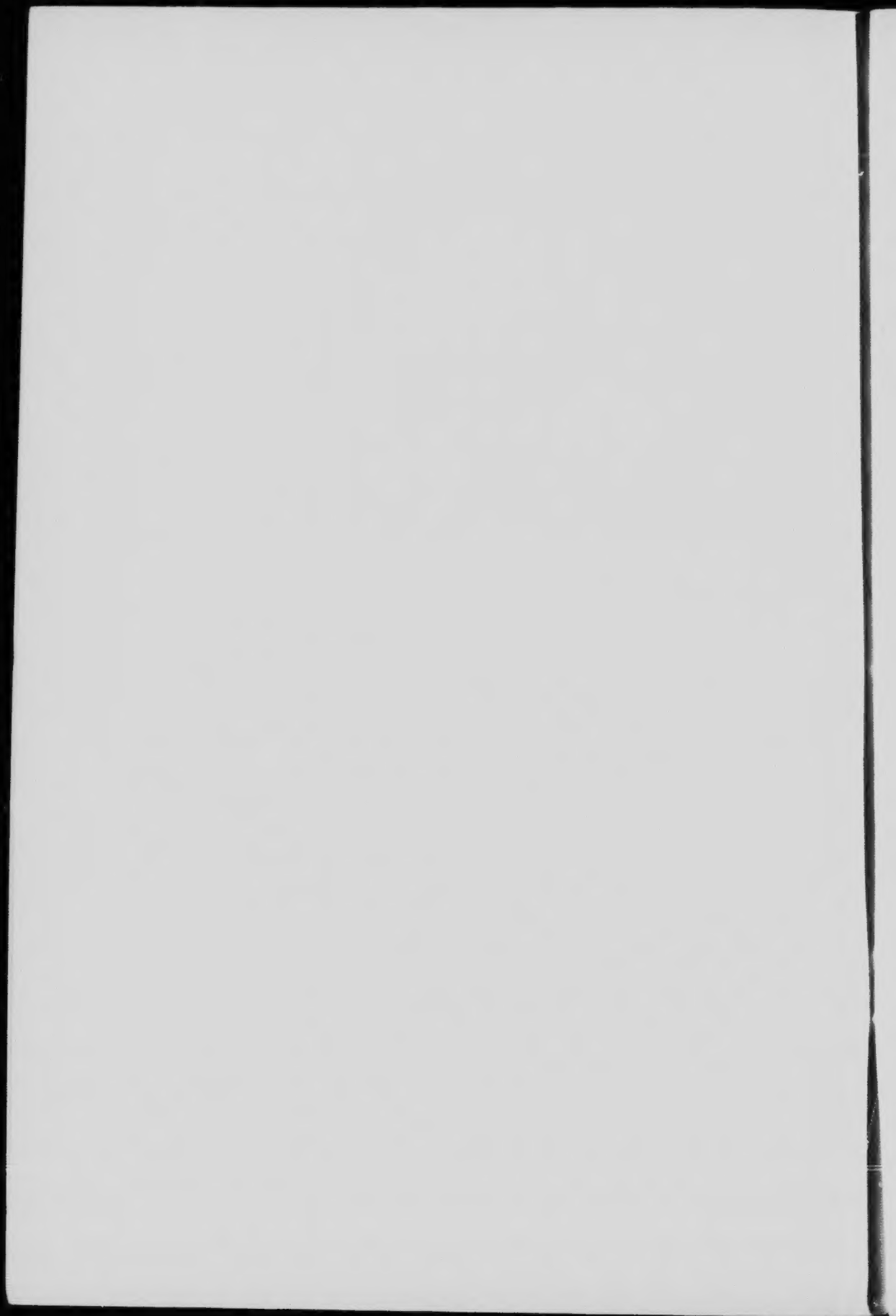


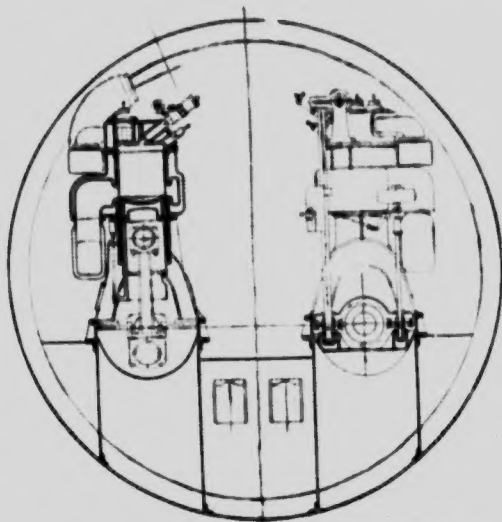
GERMAN BOAT U 15. DESTROYED IN THE NORTH SEA  
BY BRITISH WARSHIPS.



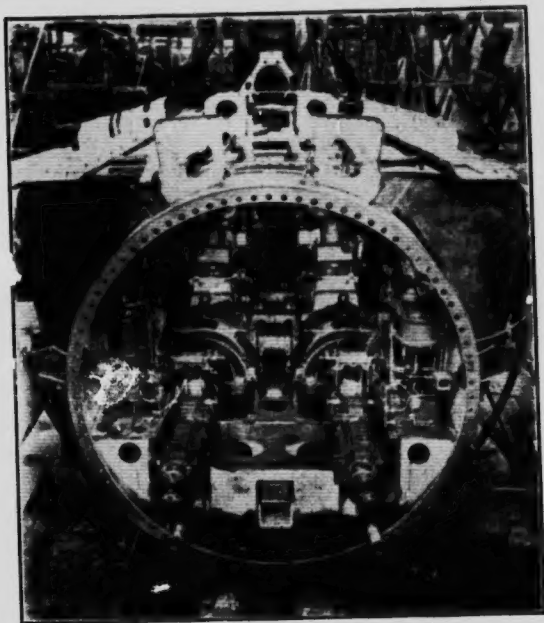
SUBMARINE HAVMANDEN—MIDSHIP SECTION.







REVERSIBLE SIX-CYLINDER DIESEL MOTOR FOR SUBMARINES.  
GERMANIA TYPE. 900 H.P. 450 REVOLUTIONS PER MINUTE.



FROM KRUPPS' GERMANIA WORKS IN KIEL.  
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